

Studying a Spacecraft Ventilation Fan: Progress and Possibilities

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This document describes a presentation delivered to the Acoustics Technical Working Group at a meeting held in Cleveland, Ohio on April 21-22, 2011. The information contained in this presentation is considered to be preliminary, intended to begin a general discussion among audience members on the challenges associated with spacecraft ventilation fans and possible avenues of continued research.

I. Introduction

At the last Acoustics Technical Working Group meeting (October 2010), it was recommended that Working Group members should refrain from presenting material that was or soon will be presented at technical conferences. Instead, thoughts and details related to current research, but not yet ready for publication, would be welcomed and used to begin open discussions. And while the majority of the material presented at past Working Group meeting focused on issues related to aircraft engine noise, Don Weir of Honeywell reminded attendees that noise is a design criterion for many mechanical systems in an aircraft including: the air generation system, conditioned service air system, temperature control system, supplemental cooling system, cabin pressure control system, auxiliary power unit, distribution system, bleed air system, and the cabin pressure control system. In response to this recommendation, NASA's recent study of a spacecraft cabin ventilation fan will be presented here.

II. Motivation

Early attention to the aerodynamic and acoustic design of spaceflight fans is intended to enable engineers to design, select, and install quieter, more efficient fans that minimize weight, volume, and power. This proactive approach aims to avoid cost and time penalties historically incurred by discovering problems late in the design cycle.

III. Plan

A plan was developed for NASA's Exploration Technology Development Program that capitalized on the research expertise from several NASA centers. That plan describes an effort to identify, design, analyze, build and test a suite of fans nominally suited for a variety of spaceflight applications. Tools and techniques used to develop quiet, high performance aircraft engine fans will be used. Results and reports will be made publicly available. This plan is described in detail in Reference 1.

IV. Progress

Design point requirements for a spacecraft cabin vent fan were identified. Daniel Tweedt generated the aerodynamic design of the fan. Design parameters are given in Table 1 and the fan aero design is plotted in Figure 1. Steady-state aerodynamic performance predictions were also obtained using a Reynolds-averaged Navier-Stokes solver for several design and off-design points. Two reports have been published by NASA describing the aero predictions for this cabin fan² and an alternate fan developed by Hamilton Sundstrand that meets the same design point conditions.³ The Hamilton Sundstrand fan represents technology currently in use on the International Space Station, and comparisons between the two fans will be useful. Hamilton Sundstrand did produce a rapid prototype of their spacecraft cabin vent fan for NASA, and this fan is available for ground testing at NASA. More recently, distorted inflow tone noise predictions have been generated. The acoustic results will be presented at NoiseCon 2011.⁴

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V. Possibilities

Many research avenues are possible, and are briefly described here. I will try to highlight the opportunities and challenges. While they are not presented in random order, the path forward is not yet well defined, either. The next step we take along this research path will be determined by staff and funding availability, as well as future spacecraft mission requirements.

A. Design a fan for ground tests

Using the aero design as a starting point, we need to complete the mechanical and electrical design of a fan suitable for validating the aerodynamic and acoustic predictions. Instrumenting the fan to obtain measurements inside the duct (which is much smaller than the fans our branch has studied in the past) will be a challenge. Fan duct pieces will need to be designed to accommodate instrumentation. The type of instrumentation needed depends upon the type of tests we want to conduct, with the choices largely falling into two categories--instrumentation for measurements inside the fan duct and instrumentation for measurements outside the fan duct.

B. Fabricate a fan for ground tests

Rapid prototyping is available as a cost-effective way to experimentally study these fans. However, there is a need to determine if there are differences in aero or acoustic performance between the rapid prototype fans and machined fans. We know, for instance, that motor noise may be a significant contributor. The motor that can be used to drive a plastic prototype fan may not be the same motor needed to drive a heavier metal fan--possibly resulting in a difference in acoustic performance between the two fans.

C. Design and fabricate a fan for spaceflight

If needed, we can modify the rapid prototype fan design to meet spaceflight requirements. Again, spaceflight requirements need to be met while minimizing noise, weight, and power and maximizing aerodynamic efficiency. Determining differences between a spaceflight fan, a metal ground test fan, and a plastic rapid prototype fan would be useful information.

D. Perform ground tests

Once instrumented, aero and acoustic tests can be performed for an isolated fan, a fan ingesting distorted inflow, and a fan installed in a ventilation system. We know that test techniques and apparatus are needed for this class of fan. We chose to study this fan not because it fit well within our existing testing capabilities, but because it fell into a known gap--and that in the course of our study we could work to fill that gap in knowledge, developing new or extending existing test methods for this class of fans. Detailed aerodynamics tests could be used to validate Computational Fluid Dynamics predictions for these low-Reynolds (Re) number fans (blade Re = 80,000, vane Re = 45,000).

E. Develop or modify international testing standards

Results of this research can be captured in international fan testing standards. Recommendations need to be shared with technical committees responsible for maintaining international standards. The INCE Technical Committee on Information Technology Noise Emissions does provide recommendations for modifying ISO10302. The duct diameter for this fan (89 mm) falls below the minimum diameter required (150 mm) by ASHRAE Standard 68—Laboratory method of testing to determine the sound power in a duct. The pressure rise at design point for this fan (925 Pa) exceeds the maximum recommended (750 Pa) in ISO 10302—Method for the measurement of airborne noise emitted by small air moving devices.

F. Develop noise prediction capabilities

NASA's existing and emerging fan noise prediction methods can be extended to address common problems in small fan systems. Inlet distortion is considered to be a dominant noise generation mechanism for spacecraft ventilation fans. Detailed aero and acoustic data is needed to validate noise prediction codes. Currently, I am using the spacecraft cabin vent fan as just another test case as I develop inflow tone noise prediction codes.

G. Publicly report findings

Results of this research can be widely disseminated via publications, presentations, and workshops. It will be challenging to represent NASA at all the conferences we currently know of that have sessions dedicated to small fan aerodynamics and acoustics. So far (since 2006), this work has only been reported at NoiseCon.

VI. Conclusion

This exercise could be a first step towards a long-term contribution. NASA could play a unique role in raising the bar on small fan aerodynamic and acoustic performance by developing a set of well-characterized, government-owned, publicly reported baseline fans nominally suited for spacecraft ventilation and cooling systems.

Acknowledgments

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References

- ¹Koch, L. D., "Quiet, Efficient Fans for Spaceflight: An Overview of NASA's Technology Development Plan," NASA TM-2010-216238, 2009.
- ²Tweedt, D. L., "Aerodynamic Design and Computational Analysis of a Spaceflight Vehicle Cabin Ventilation Fan," NASA CR- 2010-216329, 2010.
- ³Tweedt, D. L. "Computational Aerodynamic Simulations of a Spacecraft Cabin Ventilation Fan Design, NASA CR-2010-216330
- ⁴Koch, L. D., "Tone noise predictions for a spacecraft cabin ventilation fan ingesting distorted inflow and the challenges of validation," NASA TM-2011-xxxxxx, publication pending.

Table 1: Spacecraft Cabin Fan Design Point Parameters

	Predicted/Model Value
Flow rate	0.709 m ³ /s (150.3 cfm)
Total pressure rise	925 Pa (3.716 inches of water)
Pressure	101 kPa (14.7 psia)
Temperature	21.1° C (70° F)
Maximum duct diameter	0.089 m (3.5 in)
Maximum axial length	0.223 m (9.0 in)
Rotor tip clearance gap	0.23 mm (0.009 in)
Rotor speed	12,000 rpm
Number of blades	9
Number of vanes	11

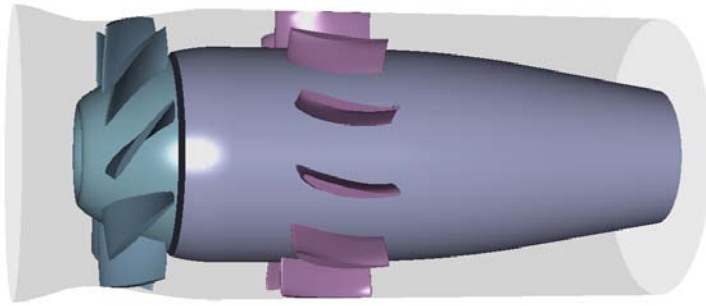


Figure 1: Side view, spacecraft cabin ventilation fan.

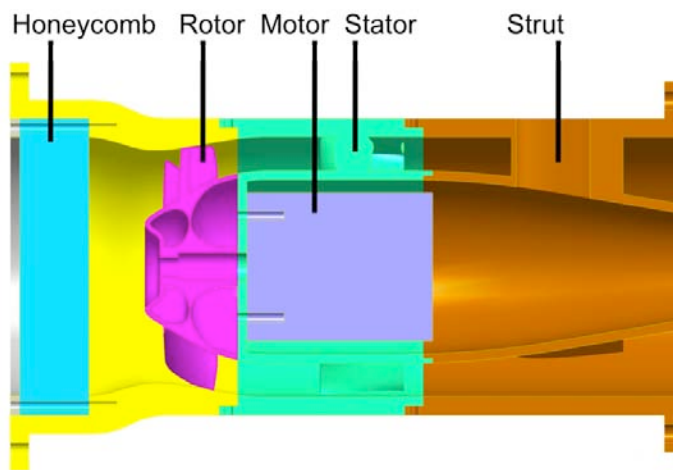


Figure 3: Cross section of conceptual design of a spacecraft cabin vent fan.



Figure 3: The spacecraft cabin vent fan can be used in ventilation system tests.